Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

1996

Compatibilfty of Refrigerants and Lubricants with Electrical Sheet Insulation Under Retrofit Conditions

R. G. Doerr
The Trane Company

T. D. Waite
The Trane Company

COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH ELECTRICAL SHEET INSULATION UNDER RETROFIT CONDITIONS[1]

Robert G. Dóerr, Ph.D. and Todd D. Waite
The Trane Company
La Crosse, Wisconsin

International Refrigeration Conference
Purdue University
West Lafayette, Indiana
July 23-26, 1996

ABSTRACT

To determine whether exposure to the original refrigerant/mineral oil would affect compatibility of sheet insulation with alternative refrigerant/lubricant after retrofit, sheet insulation was exposed at elevated temperature to the original refrigerant and mineral oil for 500 hours, followed by exposure to the alternative refrigerant and lubricant for 500 hours. Most of the sheet insulation materials exposed to the alternative refrigerant and lubricant (after an initial exposure to the original refrigerant and mineral oil) appeared to be compatible with the alternative refrigerant and lubricant. The only concern was delamination and blistering of the sheet insulation containing Nomex, especially after removal of absorbed refrigerant at high temperature. This was attributed to incompatibility of the adhesive and not to the Nomex itself. Embrittlement of the polyethylene terephthalate (PET) sheet was initially observed, but subsequent tests under extremely dry conditions showed that embrittlement of the PET materials was attributed to moisture present during the exposure.

INTRODUCTION

A primary concern in retrofitting air-conditioning and refrigeration equipment is the compatibility of the hermetic motors that have been operated with a CFC refrigerant and mineral oil for years and after conversion will be operated with the alternative refrigerant and lubricant. That prior exposure may affect the compatibility with the retrofit refrigerant and lubricant. One of the critical insulation materials of an electric motor is the sheet insulation used as slot liners and phase separators. Compatibility tests on these materials could be performed by two methods. The first method would require samples obtained from a motor that had operated in original refrigerant for years, and perform compatibility tests on those materials. This method would be subject to a number of variables, including materials identification, exposure conditions over the years, cross contamination and damage to materials on removal from an electric motor. The second method, which was actually used, started with new motor materials that were exposed at elevated temperatures to original refrigerant/mineral oil, followed by exposure to alternative refrigerant/lubricant to simulate years of exposure in the field to both refrigerants.

Underwriters Laboratories (UL) issued UL Standard 2171[3] covering retrofits. That standard requires tests after sequential exposures to the original refrigerant/lubricant followed by the alternative refrigerant/lubricant to verify the compatibility of the electrical sheet insulation. This work was conducted in accordance with the requirements of UL Standard 2171. The tests were conducted on individual samples of the electrical sheet insulation materials. Motorettes were also included to correlate with the results of tests on the individual materials. Compatibility tests of electrical sheet insulation after sequential exposures to refrigerants and lubricants were not previously conducted.

Sheet Insulation

The six electrical sheet insulations tested were the same materials tested in the prior MCLR program(2): Mylar, Melinex, Dacron-Mylar-Dacron (DMD), Nomex, Nomex-Mica, and Nomex-Mylar-Nomex (NMN). The Mylar, Melinex and Dacron-Mylar-Dacron are classified chemically as a polyethylene terephthalate (PET) and the Nomex as an aromatic polyamide or aramid fiber. These materials have been used in hermetic motors since about 1973.

Refrigerants and Lubricants

Equipment operating today with CFC's R-11, R-12 and R-502 (a HCFC-22/CFC-115 blend) and HCFC 22 are most likely to be retrofitted with HCFC's or HFC's. Lubricants for this study were randomly selected by a drawing at ARTI from a larger list of commercially available polyolesters. Because of interest in R-245ca as a possible chlorine-free replacement for R-11 or R-123, and the fact that a chiller test with R-245ca was planned in another ARTI MCLR project, the compatibility of electrical sheet insulation with R-245ca after retrofit from R-11 or R-123 was conducted. The original refrigerant and the alternative considered for retrofit were as follows:

Original Refrigerant	Alternative Refrigerant	Exposure Temperature
R-12/Mineral Oil	R-134a/Polyol Ester	127°C (260°F)
R-22/Mineral Oil	R-407C/Polyol Ester	127°C (260°F)
R-502/Mineral Oil	R-404A/Polyol Ester	127°C (260°F)
R-11/Mineral Oil	R-123/Mineral Oil	100°C (212°F)
R-11/Mineral Oil	R-245ca/Polyol Ester	100°C (212°F)
R-123/Mineral Oil	R-245ca/Polyol Ester	100°C (212°F)

Alternative refrigerant/lubricant combinations were R-407C /Polyol Ester, R-134a /Polyol Ester, R-404A /Polyol Ester, and R-245ca /Polyol Ester.

Compatibility Exposures

The compatibility exposures were based on the procedures previously used by Trane to determine the compatibility of current electrical sheet insulation and were modified to comply with UL Standard 2171. The electrical sheet insulation samples were dried for 24 hours at 127°C (260°F) and placed in two-liter, stainless steel pressure vessels. Polyolester lubricants were dried to 50 ppm moisture or less before use. Mineral oils were dried to 30 ppm or less. The original lubricant (mineral oil) was added in sufficient quantity to cover the materials, taking into consideration the thermal expansion of the lubricant and the solubility of the refrigerant. For the higher pressure refrigerants, R-12, R-502, and R-22, refrigerant was added to provide a pressure of about 2109 kPa (300 psi) at 127°C (260°F). For the low pressure refrigerant, R-11, the amount of refrigerant added was about 50% by weight. The ratio of refrigerant to lubricant ranged from approximately 20/80 for the high pressure refrigerants to 50/50 for R-11, R-123 and R-245ca depending on the solubility and pressure of the particular refrigerant/lubricant combination.

Samples were exposed to the original refrigerant and mineral oil for 500 hours at 127°C (260°F) for R-12, R-502 and R-22 or at 100°C(212°F) for R-11 and R-123 followed by exposure to the alternative refrigerant and lubricant for an additional 168, 336 and 500 hours at the same temperatures. Exposures for R-11, R-123, and R-245ca were conducted at 100°C (212°F) to prevent thermal decomposition of the least stable refrigerant, R-11.

After exposure to the original refrigerant/mineral oil for 500 hours some of the samples were removed for evaluations. Results were used as a baseline for comparison with results on the samples after exposure to the retrofit refrigerant/lubricant. Other samples from the first exposure were divided into three pressure vessels and exposed to the retrofit refrigerant/lubricant for an additional 168, 336 and 500 hours. In addition, exposures to the original refrigerant/mineral oil was continued on some samples for an additional 500 hours (1000 hours total).

Motorette samples were exposed to each combination of original refrigerant/mineral oil for 500 hours and to the alternative refrigerant/lubricant for an additional 168, 336 and 500 hours.

Evaluations

Evaluations of the electrical sheet insulation samples and the motorettes were conducted prior to exposure and after the 500 and 1000 hour exposures to the original refrigerant/mineral oil, as well as after the 168, 336 and 500 hours of additional exposures to the alternative refrigerant/lubricant. In addition to evaluations immediately after exposure, the sheet insulation were evaluated after an additional 24 hour bake in air at 127°C (260°F) to determine the effect of refrigerant desorption.

RESULTS

Condition of Materials

Sheet Insulations Exposed to R-22/R-407C, R-12/R-134a, and R-502/R-404A.

Degradation of certain sheet insulation materials was observed after the 500 and 1000 hour exposures to R-22, R-12, and R-502. Polyethylene terephthalate (PET) found in the Mylar and Melinex sheet insulations became brittle after the 1000 hour exposure to the original refrigerant/mineral oil. Blisters and delamination were noted in the Nomex-Mylar-Nomex (NMN) sheet insulations. After the 1000 hour exposures the Mylar layer in the NMN and Dacron-Mylar-Dacron (DMD) was very brittle.

A sample of Mylar MO that was embrittled after 1000 hours exposure to R-12/mineral oil was sent to Dr. Charles C. Walker of DuPont Circleville Research Laboratory for analysis. His analysis revealed that the material had an intrinsic viscosity of 0.24 which suggested that the embrittlement was caused by substantial chain cleavage through hydrolysis, rather than by thermal breakdown.

Exposure of the PET and Nomex sheet insulation to R-407C /Polyol Ester, R-134a /Polyol Ester, and R-404A /Polyol Ester, (following the R-22, R-12, and R-502 exposures with mineral oil, respectively) suggested that degradation increased less after exposure to the alternatives. Comparison of these sheet insulations after 500 hour exposure in the alternative refrigerant/lubricant and after the 1000 total hour exposures in the old refrigerant/mineral oil again indicated that exposure to the alternative refrigerant/lubricant was less severe. Motorettes with Nomex sheet insulation retained electrical integrity and there was no indication of blisters or delamination in the motorette system. The insulation materials used in the motorette were covered with varnish.

Exposure of Sheet Insulation Under Dry Conditions

Exposures of the sheet insulation to R-12/R-134a and R-22/R-407C and lubricants was repeated under dry conditions where degradation of the sheet insulation due to moisture was not expected to occur. Extra care was taken to insure that all materials were dried. The mineral oil was dried to 9.7 ppm, and motor materials were dried overnight at 127°C and for an additional four hours at 145-160°C (293-320°F). Extra care was taken to avoid moisture during the evaluations and between exposures. Sheet insulations, which became embrittled after the first exposures, remained flexible after exposures under extra dry conditions. Embrittlement of the polyester sheet insulation can be attributed to moisture. Condition of the materials are listed below.

Dry R-22/Mineral Oil and R-407C/Polyol Ester + 127° Bake

	Mylar	Melinex	DMD	Nomex	N-Mica	NMN
R-22 500 Hours	ok	ok	ok	ok	ok	Blister
R-407C 168 Hr.	ok	ok	ok	Blister	ok	Blister
R-407C 336 Hr.	ok	ok	ok	Blister	ok	Blister
R-407C 500 Hr.	ok	ok	ok	Blister	ok	Severe Blister
R-22 1000 Hr.	ok	ok	ok	ok	ok	Blister

Blisters and pockets of delamination of the Nomex composite materials still occurred under the dry conditions. Complete delamination in the original refrigerant/mineral oil was not observed. Blisters occurred in both the Nomex and Nomex-Mylar-Nomex materials. Exposure to R-12/R-134a was not as severe as R-22/R-407C. The Nomex produced no blisters and the Nomex-Mylar-Nomex exhibited only slight blisters after the 168, 336 and 500 hour exposure to R-134a, but not after the 500 and 1000 hour exposures to R-12. Under dry conditions, blistering of the Nomex composite sheet material is more prevalent in the alternative refrigerant than the original R-22 or R-12 mineral oil.

The cause of the blistering is due to absorbed refrigerant between the layers of Nomex-Mylar-Nomex attempting to escape as a vapor. The polyester adhesive absorbed refrigerant under pressure, and pressure was produced between the Nomex layers as the refrigerant vaporized. The Nomex layer was not degraded. Use of an alternative adhesive may have prevented the blister formation.

R-11/R-123 Retrofit Exposures

Tests showed that all electrical sheet insulation materials were in good condition after exposure to R-11/mineral oil for 500 hours followed by exposure to R-123/mineral oil for 168, 336, and 500 hours at 100°C (212°F). Materials evaluated at the end of the 500 hour R-123/mineral oil were compared to the same materials exposed to R-11/mineral oil for an additional 500 hours or 1000 hours total. The Dacron-Mylar-Dacron (DMD) darkened slightly in the R-123, but was darker after exposure to R-11/mineral oil. The Mylar sheet insulation and sleeving were still flexible and the Nomex 410 materials showed no signs of blistering or delamination.

Blisters were observed in the NMN after the subsequent 24 hour exposure to air at 127°C (260°F) . Motorettes maintained electrical integrity.

R-11/R-245ca and R-123/R-245ca Retrofit Tests

All electrical sheet insulation exposed to R-11/R-245ca and R-123/R-245ca remained in good condition. The Nomex-Mylar-Nomex (NMN) sheet insulation did not exhibit any blisters after the retrofit exposure, but blisters were produced in the NMN after the subsequent 24 hour exposure to air at 127°C (260°F).

Electrical and Mechanical Property Measurements.

Trends and conclusions are discussed in the following section. Additional information and the complete set of data is available in the final report.[1]

Sheet Insulation

The sheet insulation materials were most affected by exposures to the refrigerants/lubricants under retrofit conditions. Embrittlement of the PET material and delamination of the DMD or NMN had an effect on the tensile strength and percent elongation. The dielectric strength was not affected. In most of the dielectric tests, the spark would travel around the 2 x 3 inch samples rather than through the material. Dielectric strengths were recorded as greater than the recorded voltage (>_kV), rather than percent change.

Exposure of the sheet insulations to R-502/R-404A resulted in embrittlement of the PET materials and delamination of the NMN composite. Embrittlement was most pronounced after the 1000 hour exposure to R-502/mineral oil, but also resulted in a decrease in the percent elongation after the 500 hour exposure to R-404A/polyolester lubricant. Tensile strength of the PET decreased by about 20% after the R-404A exposure. In some cases there appeared to be a trend of decreasing percent elongation with exposure time, but experimental deviation predominated in at least half of the data sets. Dielectric strength of all sheet insulation was not decreased and in most cases actually increased.

Exposure of sheet insulation to R-22/R-407C resulted in embrittlement of the PET materials and delamination of the NMN. This had an effect on the tensile strength and percent elongation. Exposure to R-22/mineral oil for 1000 hours caused embrittlement of the PET to the extent that tensile strength and percent elongation of the PET material could not be determined. Results at the other conditions showed decreased tensile strength and percent elongation with increased time of exposure. For example the tensile strength of Mylar decreased -28.2%, -31.3% and -32.5% from 168, 336 and 500 hours exposure to R-407C, and percent elongation decreased -38.2%, -71.9% and -84.3%, respectively. The DMD form of PET showed similar behavior. With other sheet insulation materials the effect of time on tensile strength and elongation was inconclusive. Dielectric strength was unaffected.

Exposure of sheet insulation to R-12/R-134a showed similar results to that of R-22/R-407C. The PET tensile strength and percent elongation decreased with time of exposure and was most severe after 1000 hours in R-12/mineral oil. The dielectric strength usually increased after exposure to refrigerant lubricant.

Sheet Insulation Under Dry conditions

The exposure of sheet insulation to R-22/R-407C and R-12/R-134a was repeated to determine if extra care in drying would prevent embrittlement of the PET materials and blistering of the NMN. Care was taken to dry materials both before and between the exposures. Results showed that observed embrittlement of the PET materials was prevented, but tensile strength and percent elongation were severely reduced. Blistering of the Nomex-Mylar-Nomex still occurred.

In the R-11 to R-123 retrofit scenario, the lubricant remained the same, namely mineral oil. A small amount of moisture in mineral oil had a greater effect on hydrolysis of PET materials than larger amounts of moisture in polyolester lubricant due to solvolysis of the water by the ester lubricant. The PET sheet insulation appeared satisfactory after the 1000 hour exposure to R-11 or R-11/R-123, but the percent elongation was severely reduced, especially after the 24 hour bake. Tensile strength was reduced by only 25% for the same materials. There was a trend toward increased embrittlement, and decreased tensile strength as the exposure to R-123 increased from 168 to 326 to 500 hours. There was no evidence of delamination and dielectric strength was retained.

Exposure to R-245ca polyolester after exposure to either R-11 or R-123 mineral oil resulted in blisters in the NMN after the 127°C bake, but little embrittlement of the PET sheet insulation. Percent elongation actually increased slightly from the 118% in R-123 to 134% (same as the unexposed value) in R-245ca. The dielectric remained the same.

Motorettes

All motorettes passed the voltage withstand test (600 volts for one minute applied between windings, windings & ground, and turn to turn) after exposure to the original refrigerant/mineral oil followed by the alternative refrigerant/lubricant.

CONCLUSION

Most of the electrical sheet insulation appeared to be compatible with the alternative refrigerants and lubricants after retrofit from the original refrigerant and mineral oil, The major concern was delamination and blistering of the Nomex composite sheet insulation. The embrittlement observed in the PET insulation materials was thought to be due to hydrolysis from moisture present in the insulation and in the lubricant during the compatibility exposure. Tests were repeated with very dry PET insulation and lubricants. Embrittlement was not observed. The electrical insulation materials were either unaffected or affected by the old refrigerant/mineral oil to a similar or greater extent than by the alternative refrigerant and lubricant. These electrical sheet insulation materials have an excellent history of reliability in R-22, R-12, R-502, and R-11, and should offer equal or superior reliability with the alternative refrigerants and lubricants.

REFERENCES

(1) R. G. Doerr and T.D. Waite, **"Compatibility of Refrigerants and Lubricant with Motor Materials Under Retrofit Conditions," Final Report DOE/CE23810-63.** Air Conditioning and Refrigeration Technology Institute (ARTI) , 1996

(2) R. G. Doerr and S. A. Kujak, **"Compatibility of Refrigerants and Lubricant with Motor Materials," Final Report DOE/CE23810-13.** Air Conditioning and Refrigeration Technology Institute (ARTI), May 1993.

(3) UL Standards 2171; **Field Conversion/ Retrofit of Products to Change to an Alternative Refrigerant - Insulating Material and Refrigerant Compatibility**; Underwriters Laboratory, Sept.17,1993.